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The relationship of the change of corneal power to the change in total refractive power of the eye with age

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Abstract

The purpose of this thesis is to compare the change of astigmatism of the eye as determined by subjective methods (#7a) to the change of astigmatism found on the front surface of the cornea as measured by the Ophthalmometer. The approximate ages of sixty and seventy were chosen for sampling.

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THE RELATIONSHIP OF THE CHANGE OF CORNEAL POWER TO THE CHANGE IN TOTAL REFRACTIVE POWER OF THE EYE WITH AGE

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PURPOSE

The purpose of this thesis is to compare the change of astigmatism of the eye as determined by subjective methods (#7a) to the change of astigmatism found on the front surface of the cornea as measured by the Ophthalmometer. The approximate ages of sixty and seventy were chosen for sampling.

REVIEW OF THE LITERATURE

As a result of reading the following statement in "Vision of the Aging Patient" this research was done.

> " The present consensus is that the basis for this change in astigmatism from with-the-rule to against the-rule with advancing age rests in the crystalline lens and not in the cornea " (1)

It is assumed by Hirsch and others that this change in astigmatism from with-the-rule to against-the-rule with age is due to lenticular changes, but no convincing evidence is ever presented. (2)

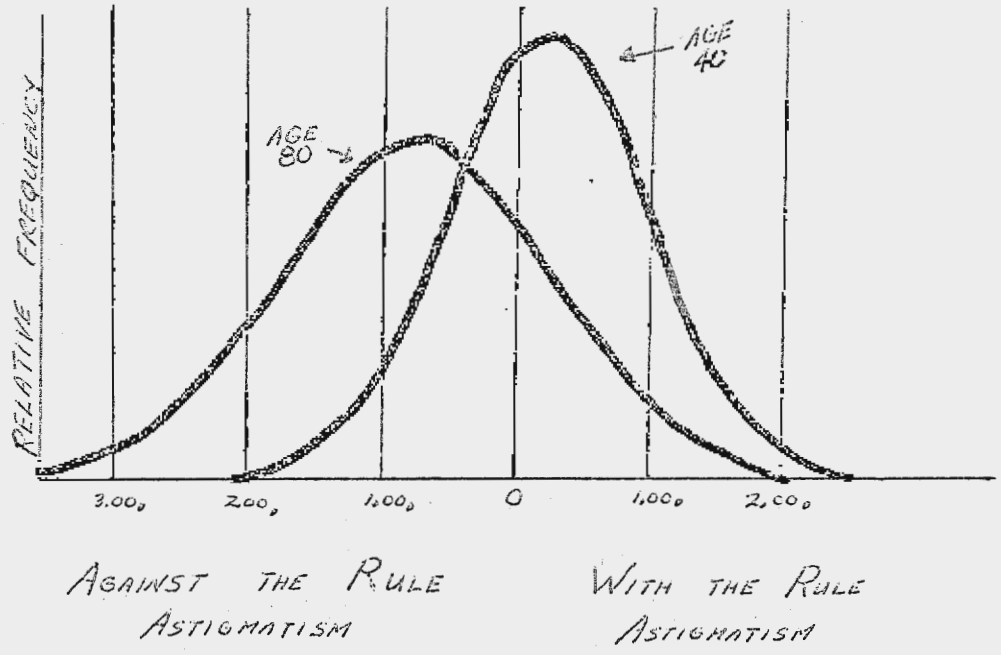
Mean, Median, and Standard Deviation of Astigmatism for ages from 40 to over 80

Age group	Number	Mean	Median	Standard Deviation
40-44	164	+0.27	+0.09	0.84
45-49	166	-0.09	-0.08	0.74
50-54	174	-0.12	-0.05	0.83
55-59	168	-0.22	-0.20	0.91
60-64	167	-0.27	-0.38	0.85
65-69	170	-0.41	-0.48	0.89
70-74	144	-0.43	-0.58	1.15
75-79	107	-0.70	-0.63	0.98
Over 80	93	-0.81	-0.91	0.93

On the basis of his data Hirsch concluded that between the ages of 40 and 80 both the mean and the median demonstrate a change of approximately 1.00 D.

in the direction of increased against-the-rule astigmatism. The standard deviation increases about 0.25 D. during this period. The distribution of astigmatism at all ages does not differ significantly from a normal curve. Based on these findings, a normal curve for the distribution of astigmatism at age 40 and at age 80 may be constructed to demonstrate graphically the change that occurs over this 40 year period. (3) The graph is shown below:

Refractive Changes with Age



" From this graph no attempt has been made to ascertain the cause of this change of astigmatism." (4)

Helmholtz states, " The limit of normal astigmatism of the eye probably should be given as 0.5 Diopters, with the direct (with-the-rule) form being more common in youth and the inverse form (against-the-rule) more common in advanced life. (5)

In all of the studies attempted sex showed little difference thus the data for male and female has been combined. (6)

Astigmatism as a visual anomaly was late to be considered. In 1801 Thomas Young demonstrated this phenomenon in his own eye and demonstrated that most of the astigmatism was present at the cornea. The first carefully executed measurements of the corneal surface were done by Helmholtz after his development of the Ophthalmometer. (7)

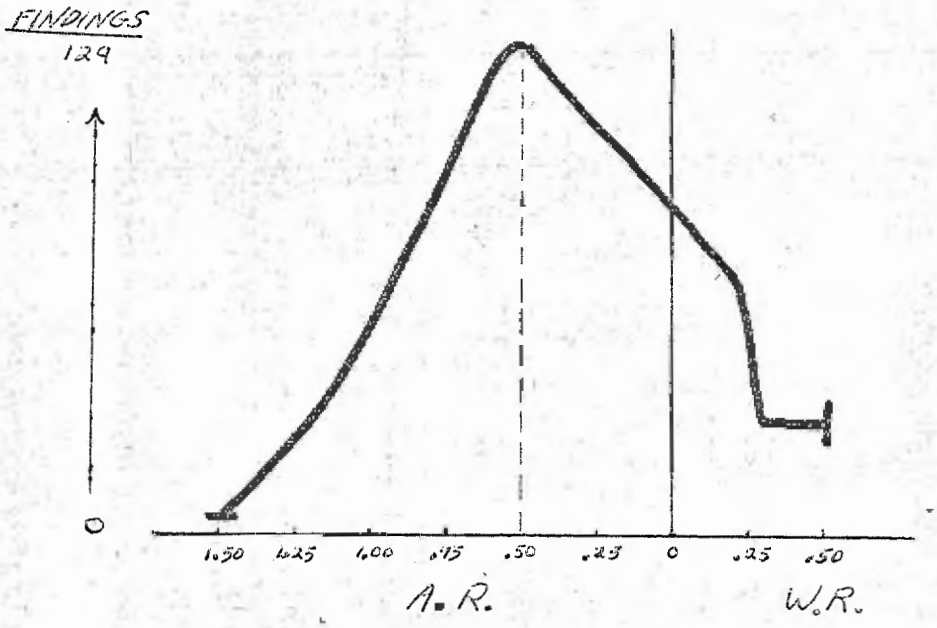
Bull in 1890 published the graph shown below which is the causative factor in Javal's Rule.

$$\text{Ast.} = K - .50 \times 90$$

By the graph it is readily seen that the average difference between corneal astigmatism and overall astigmatism of the eye is equal to .50 Diopters. It was suggested by Ostwalt that a portion of this error was due to the difference in effectivity of lenses when projected to the corneal plane. After this was taken into consideration the Javal's Rule was changed to : (8)

Ast. = 1.25 K - .50 X 90

Findings Difference in Diopters
between
Corneal Astigmatism and Subjective Cylinder



Many of the authorities in the field of Astigmatism feel that the factor of Physiological Astigmatism must be considered as it is a factor in the overall astigmatism of the eye. The definition of Physiological or Residual Astigmatism has been : the astigmatism due to

all the surfaces of the ocular body excluding the amount due to the cornea. Possible causes of this phenomena of Physiological Astigmatism as stated by Sheard are : (9)

1) Lack of centering of Optical elements of the eye due to angle Alpha.
2) Astigmatism due to lens obliquity.
3) Astigmatic Accommodation.

PROCEDURE

Data from the Pacific University files was used as the basis for this study. Names of those persons close to seventy years of age in 1965 were recorded. From these the Ophthalmometer readings and subjective to best visual acuity (#7a) were recorded for all persons having at least nine years of previous records.

For these individuals the power was calculated for the 180th and 90th meridians for both the Ophthalmometer and #7a findings, using the graph as illustrated. * This was done for each subject, for two ages lying close to ten years apart.

The change in power, in diopters per year, was calculated for the two meridians of both findings, giving the average change for this ten year interval. From this information four cumulative frequency diagrams were constructed corresponding to power changes of the Ophthalmometer at 180th and 90th meridians and power change of the #7a at 180th and 90th meridians. ** Observation of the graphs showed twelve eyes in which the change of #7a was markedly toward minus with age in the 70's.

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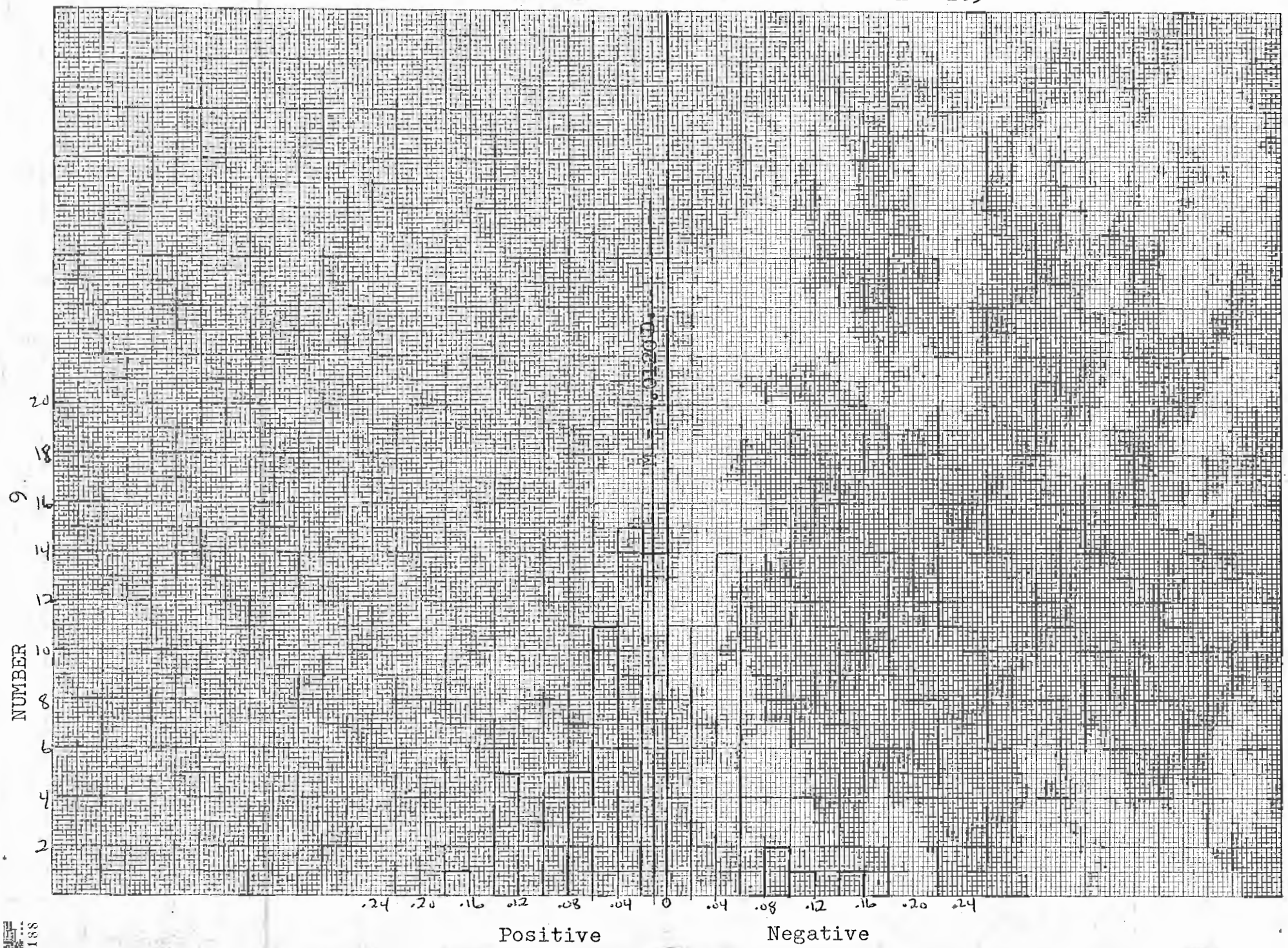
* Graph and illustration of method found on Page 29
** Cumulative frequency diagrams found on Page 9

("second sight") which change was opposite to and far outside the approximately normal distribution of the majority. The deviate subjects were eliminated from the study with 105 eyes remaining for statistical study and analysis.

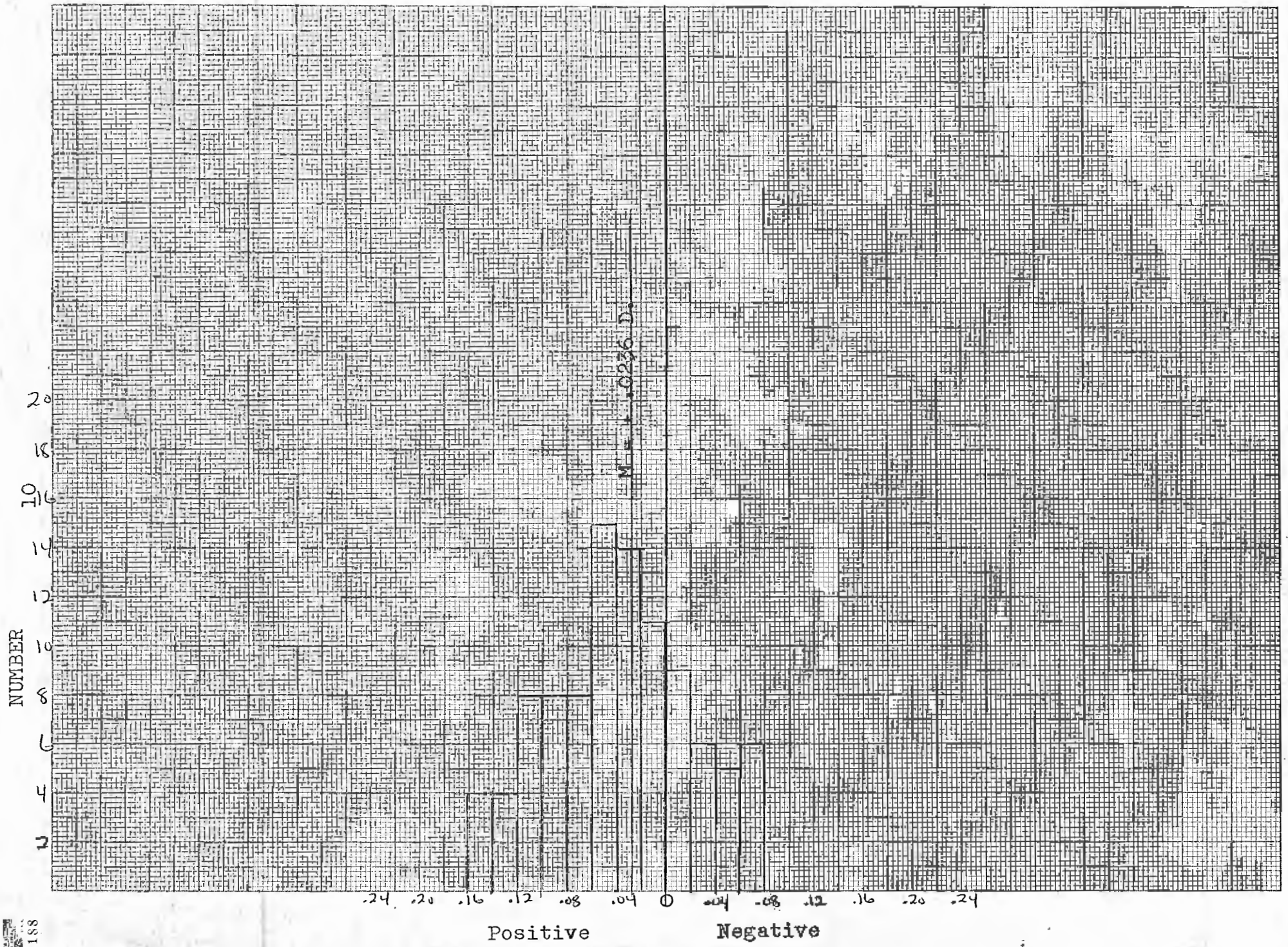
K @ 180 CHANGE IN POWER PER YEAR IN DIOPTERS n = 105



12-188

10 Millimeters to the Centimeter

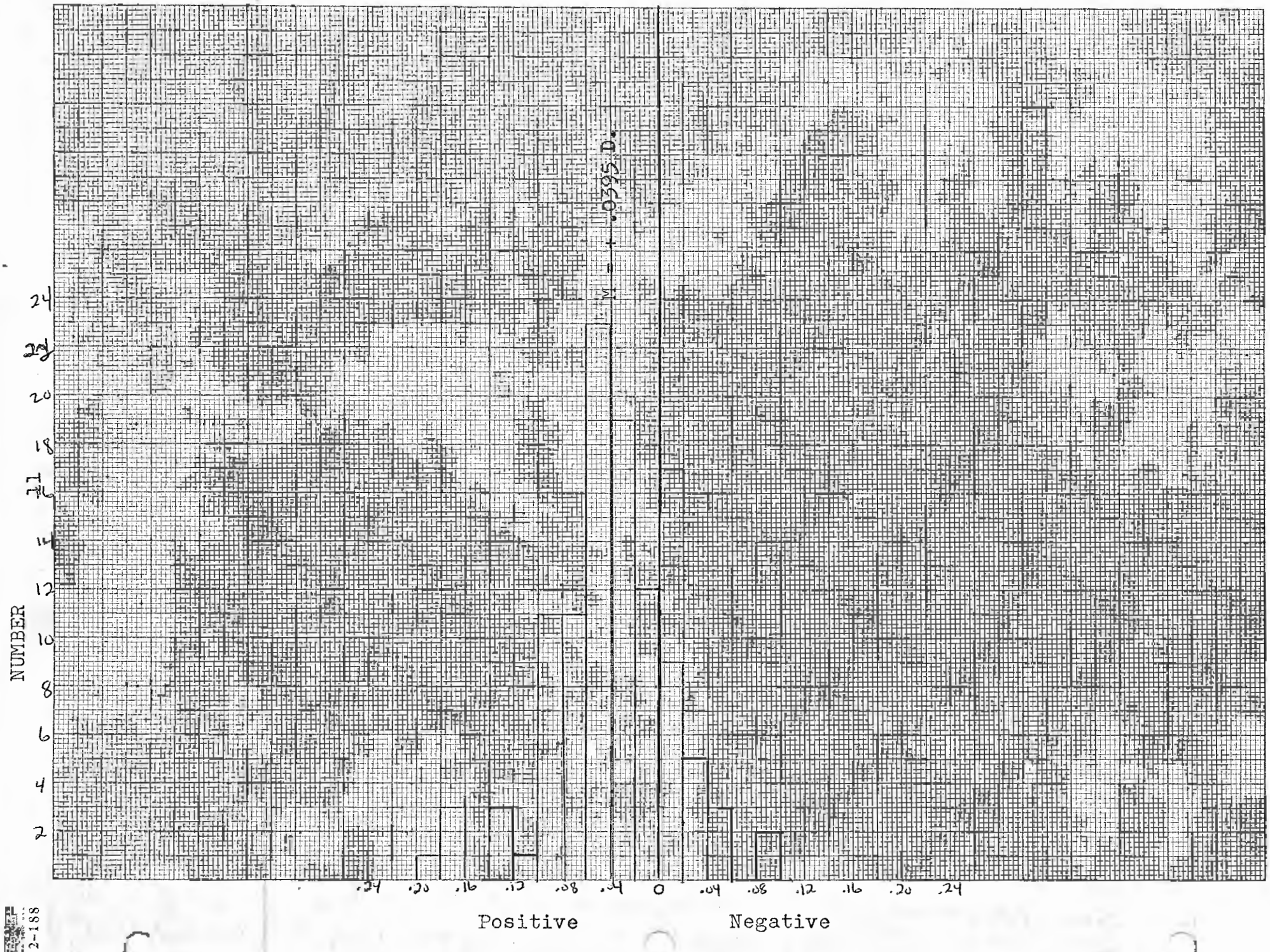
K @ 90 CHANGE IN POWER PER YEAR IN DIOPTERS n = 105



12-188

10 Millimeters to the Centimeter

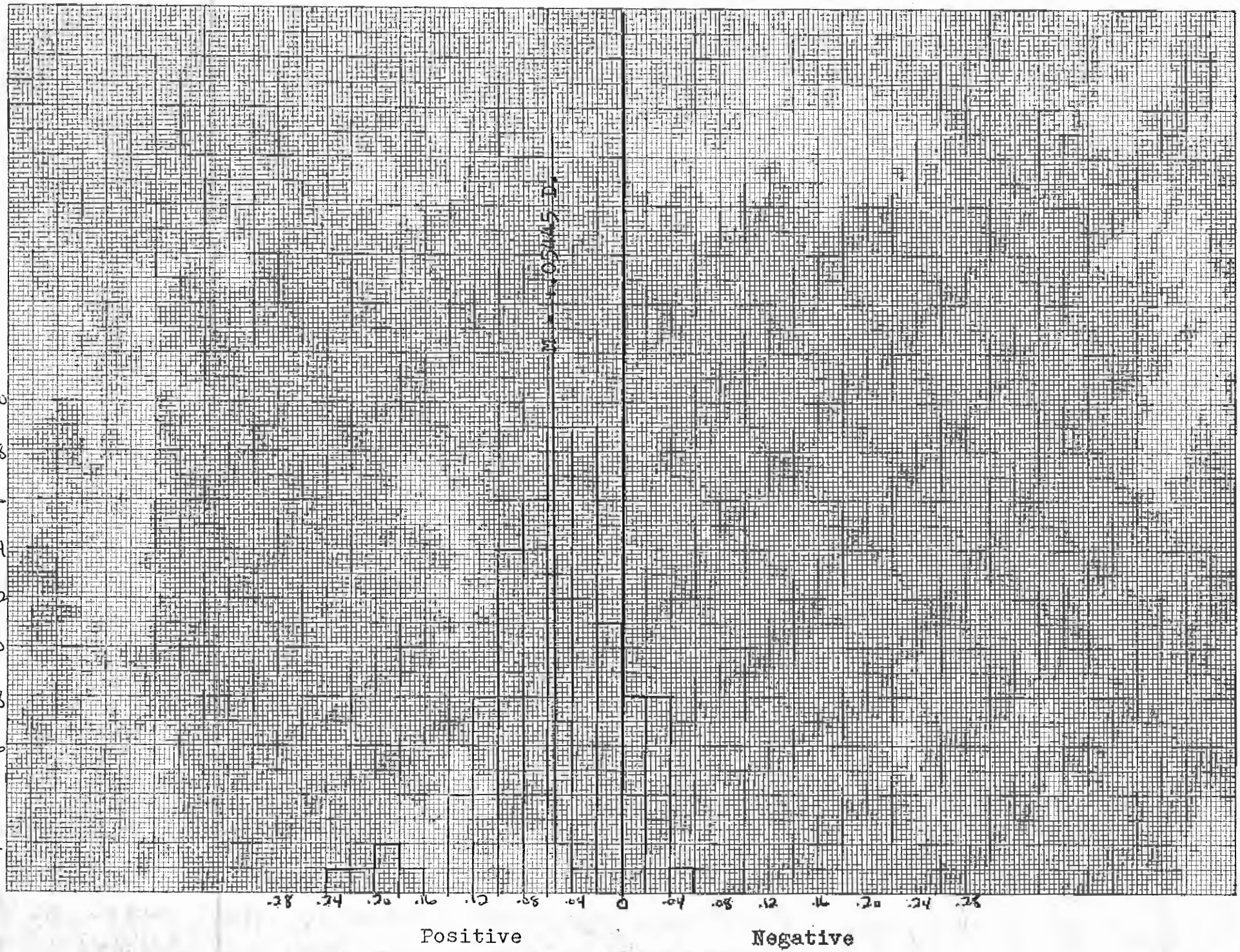
#7a @ 180 CHANGE IN POWER PER YEAR IN DIOPTERS n = 105



12-188

10 Millimeters to the Centimeter

#7a @ 90 CHANGE IN POWER PER YEAR IN DIOPTERS n = 105



12-188

10 Millimeters to the Centimeter

ANALYSIS OF DATA

Formulas used for statistical analysis of the data:

1) Mean Value :

$$\bar{x} = \frac{\Sigma X}{n}$$

2) Standard Deviation :

$$\sigma = \sqrt{\frac{\Sigma d^2}{n}}$$

3) Standard Error of the Mean :

$$S.E.M. = \frac{\sigma}{\sqrt{n}}$$

4) "t" Score for Determinate Value of Significance :

$$"t" = \frac{\bar{x} - \bar{x}}{\sqrt{\frac{(\sigma \bar{x}\ 180) + (\sigma \bar{x}\ 90)}{n_1 + n_2 - 2}}}$$

Compiled data sheet :

1) Compiled data for all 105 eyes.

A.

Heading	K @180	K @90	7a @180	7a @90
Sum chg. in D./yr.	+1.260	+2.481	+4.144	+5.717
Mean chg. in D./yr.	+0.012	+0.024	+0.040	+0.054
d^2	+0.250	+0.292	+0.319	+0.285
$\frac{d^2}{n}$	0.00238	0.00269	0.00304	0.00271
σ	0.050	0.053	0.055	0.052
S.E.M.	0.0049	0.0052	0.0054	0.0051
"t" Score	----- 7.25 -----		----- 6.23------	

B. Age distribution.

Average oldest age	70.10 years
Average youngest age	58.90 years
Average age span	11.20 years

C. Total refractive changes(spherical Eq.)

Average refractive error at 58.90yr.	+1.17 D.
Average refractive error at 70.10yr.	+1.65 D.
Average change over 11.20 yr. period.	+0.48 D.

2) Compiled data for right eyes. n = 51

A.

Heading	K @180	K @90	7a @180	7a @90
Sum chg. in D./yr.	+.380	+1.533	+2.256	+2.804
Mean chg. in D./yr.	+.0076	+.0301	+.0439	+.0550
d^2	.1928	.1754	.1551	.1348
$\frac{d^2}{n}$	.0039	.0034	.0030	.0026
σ	.0615	.0587	.0552	.0514
S.E.M.	.0086	.0082	.0077	.0072
"t" Score	----- 9.48 -----		----- 4.66 -----	

3) Compiled data for left eyes. n = 54

A.

Heading	K @180	K @90	7a @180	7a @90
Sum chg. in D./yr.	+1.318	+1.996	+1.572	+2.939
Mean chg. in D./yr.	+.0244	+.0370	+.0290	+.0544
d^2	.1845	.1723	.0830	.1148
$\frac{d^2}{n}$	.0034	.0032	.0015	.0021
σ	.0584	.0565	.0392	.0462
S.E.M.	.0080	.0077	.0053	.0063
"t" Score	----- 4.83 -----		----- 13.65 -----	

CALCULATIONS

Calculations for all 105 eyes :

1. Mean ages :

   a. First reading.

$$\bar{X}_1 = \frac{\Sigma X_1}{n} = \frac{6182}{105} = 58.9 \text{ YEARS}$$

   b. Final reading.

$$\bar{X}_2 = \frac{\Sigma X_2}{n} = \frac{7356}{105} = 70.1 \text{ YEARS}$$

   c. Average age span.

$$70.1 - 58.9 = 11.2 \text{ YEARS}$$

2. Mean change in diopters per year.

$$\bar{X}_{K\,180} = \frac{\Sigma X_{K\,180}}{n} = \frac{+1.260}{105} = +0.012 \text{ D/YR.}$$

$$\bar{X}_{K\,90} = \frac{\Sigma X_{K\,90}}{n} = \frac{+2.481}{105} = +0.0236 \text{ D/YR}$$

$$\bar{X}_{7A\,180} = \frac{\Sigma X_{7A\,180}}{n} = \frac{+4.144}{105} = +0.0395 \text{ D/YR}$$

$$\bar{X}_{7A\,90} = \frac{\Sigma X_{7A\,90}}{n} = \frac{+5.712}{105} = +0.054 \text{ D/YR}$$

3. Standard Deviation.

$$\sigma_{K180} = \sqrt{\frac{\Sigma (d_{K180})^2}{N}} = \sqrt{\frac{0.250472}{105}} = 0.0491$$

$$\sigma_{K90} = \sqrt{\frac{\Sigma (d_{K90})^2}{N}} = \sqrt{\frac{0.292394}{105}} = 0.0530$$

$$\sigma_{TA180} = \sqrt{\frac{\Sigma (d_{TA180})^2}{N}} = \sqrt{\frac{0.318692}{105}} = 0.0552$$

$$\sigma_{TA90} = \sqrt{\frac{\Sigma (d_{TA90})^2}{N}} = \sqrt{\frac{0.28474}{105}} = 0.0522$$

4. Standard Error of the Mean.

$$SEM_{K180} = \frac{\sigma_{K180}}{\sqrt{N}} = \frac{0.0491}{\sqrt{105}} = 0.00488$$

$$SEM_{K90} = \frac{\sigma_{K90}}{\sqrt{N}} = \frac{0.053}{\sqrt{105}} = 0.00518$$

$$SEM_{TA180} = \frac{\sigma_{TA180}}{\sqrt{N}} = \frac{0.0552}{\sqrt{105}} = 0.00539$$

$$SEM_{TA90} = \frac{\sigma_{TA90}}{\sqrt{N}} = \frac{0.0522}{\sqrt{105}} = 0.00509$$

5. "t" Score.

$$t_K = \frac{\bar{X}_{K180} - \bar{X}_{K90}}{\sqrt{\frac{(\sigma_{K180})^2 + (\sigma_{K90})^2}{n_{K180} + n_{K90} - 2}}} = \frac{+0.012 - 0.0236}{\sqrt{\frac{(.0491)^2 + (.053)^2}{105 + 105 - 2}}}$$

$$t_K = \frac{-0.0116}{\sqrt{\frac{0.00533}{108}}} = \frac{-0.0116}{0.0016} = \underline{7.25}$$

$$t_{7A} = \frac{\bar{X}_{7A\,180} - \bar{X}_{7A\,90}}{\sqrt{\frac{(\sigma_{7A\,180})^2 + (\sigma_{7A\,90})^2}{n_{7A\,180} + n_{7A\,90} - 2}}} = \frac{+0.0395 - 0.054}{\sqrt{\frac{(.0552)^2 + (.0522)^2}{105 + 105 - 2}}}$$

$$t_{7A} = \frac{-0.0145}{\sqrt{\frac{0.00576}{108}}} = \frac{-0.0145}{0.00233} = \underline{6.23}$$

Calculations for right eyes :

1. Mean change in diopters per year.

$$\bar{X}_{K\,180} = \frac{\Sigma x_{K\,180}}{n} = \frac{+.380}{51} = +0.0076 \text{ D/YR}$$

$$\bar{X}_{K\,90} = \frac{\Sigma x_{K\,90}}{n} = \frac{+1.533}{51} = +0.0301 \text{ D/YR}$$

$$\bar{X}_{TA\,180} = \frac{\Sigma x_{TA\,180}}{n} = \frac{+2.256}{51} = +0.0439 \text{ D/YR}$$

$$\bar{X}_{TA\,90} = \frac{\Sigma x_{TA\,90}}{n} = \frac{+2.804}{51} = +0.055 \text{ D/YR}$$

2. Standard Deviation.

$$\sigma_{K\,180} = \sqrt{\frac{\Sigma (d_{K\,180})^2}{N}} = \sqrt{\frac{0.1928}{51}} = 0.0615$$

$$\sigma_{K\,90} = \sqrt{\frac{\Sigma (d_{K\,90})^2}{N}} = \sqrt{\frac{0.1754}{51}} = 0.0587$$

$$\sigma_{TA\,180} = \sqrt{\frac{\Sigma (d_{TA\,180})^2}{N}} = \sqrt{\frac{0.1551}{51}} = 0.0552$$

$$\sigma_{TA\,90} = \sqrt{\frac{\Sigma (d_{TA\,90})^2}{N}} = \sqrt{\frac{0.1348}{51}} = 0.0514$$

3. Standard Error of the Mean.

$$SEM_{K\,180} = \frac{\sigma_{K\,180}}{\sqrt{N}} = \frac{0.0615}{\sqrt{51}} = 0.00860$$

$$SEM_{K\,90} = \frac{\sigma_{K\,90}}{\sqrt{N}} = \frac{0.0587}{\sqrt{51}} = 0.00821$$

$$SEM_{9A\,180} = \frac{\sigma_{9A\,180}}{\sqrt{N}} = \frac{0.0552}{\sqrt{51}} = 0.00772$$

$$SEM_{9A\,90} = \frac{\sigma_{9A\,90}}{\sqrt{N}} = \frac{0.0514}{\sqrt{51}} = 0.00718$$

4. "t" Score

$$t_K = \frac{\bar{X}_{K\,180} - \bar{X}_{K\,90}}{\sqrt{\frac{(\sigma_{K\,180})^2 + (\sigma_{K\,90})^2}{n_{K\,180} + n_{K\,90} - 2}}} = \frac{+.0076 - 0.0301}{\sqrt{\frac{(.0615)^2 + (.0587)^2}{51 + 51 - 2}}}$$

$$t_K = \frac{-0.0254}{\sqrt{\frac{0.00722}{100}}} = \frac{-0.0254}{0.00268} = \underline{9.48}$$

$$t_{9A} = \frac{\bar{X}_{9A\,180} - \bar{X}_{9A\,90}}{\sqrt{\frac{(\sigma_{9A\,180})^2 + (\sigma_{9A\,90})^2}{n_{9A\,180} + n_{9A\,90} - 2}}} = \frac{0.0439 - 0.055}{\sqrt{\frac{(.0552)^2 + (.0514)^2}{51 + 51 - 2}}}$$

$$t_{9A} = \frac{-0.0111}{\sqrt{\frac{0.00569}{100}}} = \frac{-0.0111}{0.00238} = \underline{4.66}$$

Calculations for left eyes:

1. Mean change in diopters per year.

$$\bar{X}_{K180} = \frac{\Sigma x_{K180}}{n} = \frac{+1.318}{54} = +0.0244$$

$$\bar{X}_{K90} = \frac{\Sigma x_{K90}}{n} = \frac{+1.996}{54} = +0.037$$

$$\bar{X}_{7A\ 180} = \frac{\Sigma x_{7A180}}{n} = \frac{+1.572}{54} = +0.029$$

$$\bar{X}_{7A\ 90} = \frac{\Sigma x_{7A90}}{n} = \frac{+2.939}{54} = +0.0544$$

2. Standard Deviation .

$$\sigma_{K180} = \sqrt{\frac{\Sigma (d_{K180})^2}{N}} = \sqrt{\frac{0.1845}{54}} = 0.0584$$

$$\sigma_{K90} = \sqrt{\frac{\Sigma (d_{K90})^2}{N}} = \sqrt{\frac{0.1723}{54}} = 0.0565$$

$$\sigma_{7A\ 180} = \sqrt{\frac{\Sigma (d_{7A\ 180})^2}{N}} = \sqrt{\frac{0.0830}{54}} = 0.0392$$

$$\sigma_{7A\ 90} = \sqrt{\frac{\Sigma (d_{7A\ 90})^2}{N}} = \sqrt{\frac{0.1148}{54}} = 0.0462$$

3. Standard Error of the Mean.

$$SEM_{K180} = \frac{\sigma_{K180}}{\sqrt{N}} = \frac{0.0584}{\sqrt{54}} = 0.00795$$

$$SEM_{K90} = \frac{\sigma_{K90}}{\sqrt{N}} = \frac{0.0565}{\sqrt{54}} = 0.00769$$

$$SEM_{\eta A\,180} = \frac{\sigma_{\eta A\,180}}{\sqrt{N}} = \frac{0.0392}{\sqrt{54}} = 0.00533$$

$$SEM_{\eta A\,90} = \frac{\sigma_{\eta A\,90}}{\sqrt{N}} = \frac{0.0462}{\sqrt{54}} = 0.0628$$

4. "t" Score.

$$t_K = \frac{\bar{X}_{K180} - \bar{X}_{K90}}{\sqrt{\frac{(\sigma_{K180})^2 + (\sigma_{K90})^2}{n_{K180} + n_{K90} - 2}}} = \frac{+0.0244 - 0.037}{\sqrt{\frac{(.0584)^2 + (.0565)^2}{54 + 54 - 2}}}$$

$$t_K = \frac{-.0126}{\sqrt{\frac{0.00661}{106}}} = \frac{-.0126}{0.00261} = \underline{4.83}$$

$$t_{\eta A} = \frac{\bar{X}_{\eta A\,180} - \bar{X}_{\eta A\,90}}{\sqrt{\frac{(\sigma_{\eta A\,180})^2 + (\sigma_{\eta A\,90})^2}{n_{\eta A\,180} + n_{\eta A\,90} - 2}}} = \frac{+0.029 - 0.0544}{\sqrt{\frac{(0.0392)^2 + (0.0462)^2}{54 + 54 - 2}}}$$

$$t_{\eta A} = \frac{-0.0254}{\sqrt{\frac{0.00366}{106}}} = \frac{-0.0254}{0.00186} = \underline{13.65}$$

COMPARISON OF "t" SCORE COEFFICIENTS

Element	Calculated "t" score	"t" Significance Levels with 100 df		
		.05	.01	.001
t_K	7.25	1.984	2.626	3.347
t_{Th}	6.23	1.984	2.626	3.347

Element	Calculated "t" score	"t" Significance levels with 50 df		
		.05	.01	.001
$t_{K\,od}$	9.48	2.008	2.678	3.596
$t_{Th\,od}$	4.66	2.008	2.678	3.596
$t_{K\,os}$	4.83	2.008	2.678	3.596
$t_{Th\,os}$	13.65	2.008	2.678	3.596

ANALYSIS

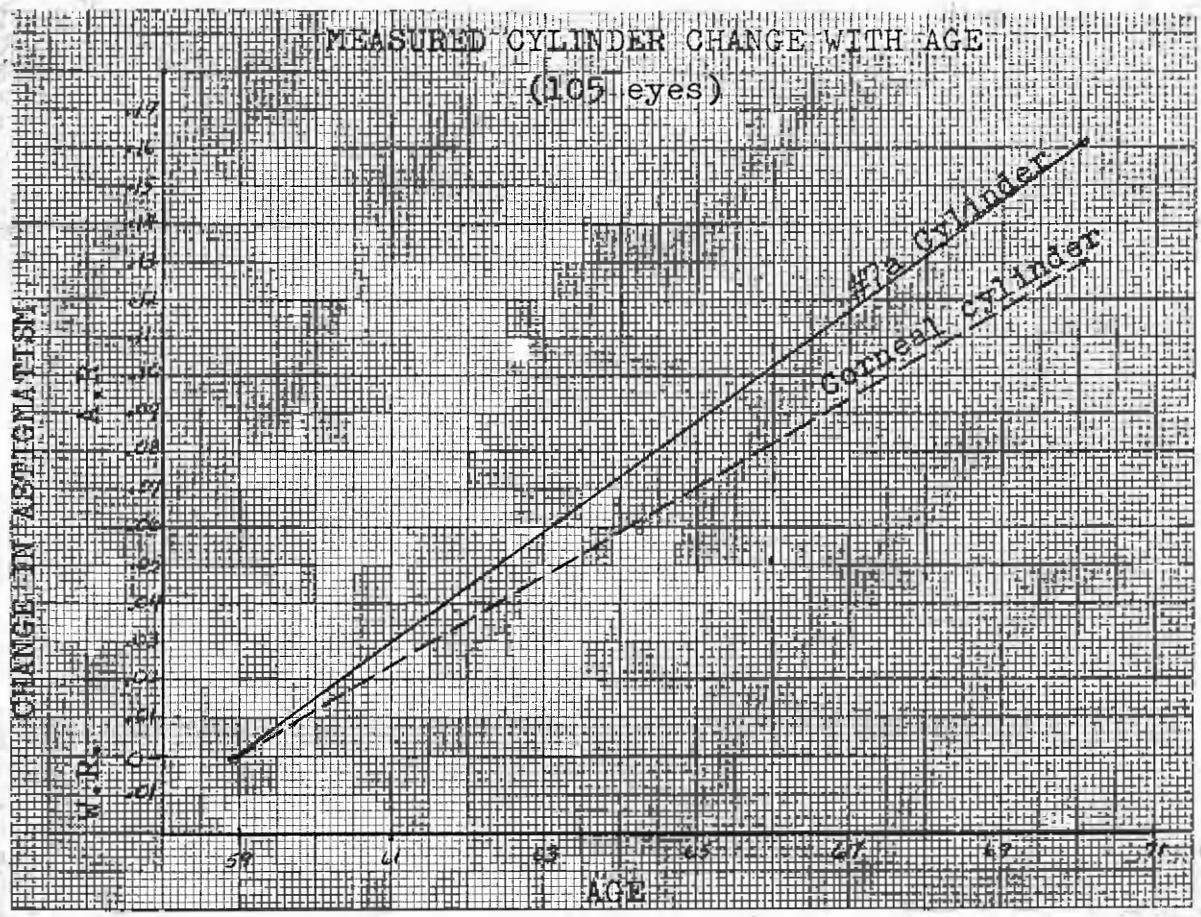
(With reference to compiled data sheet)

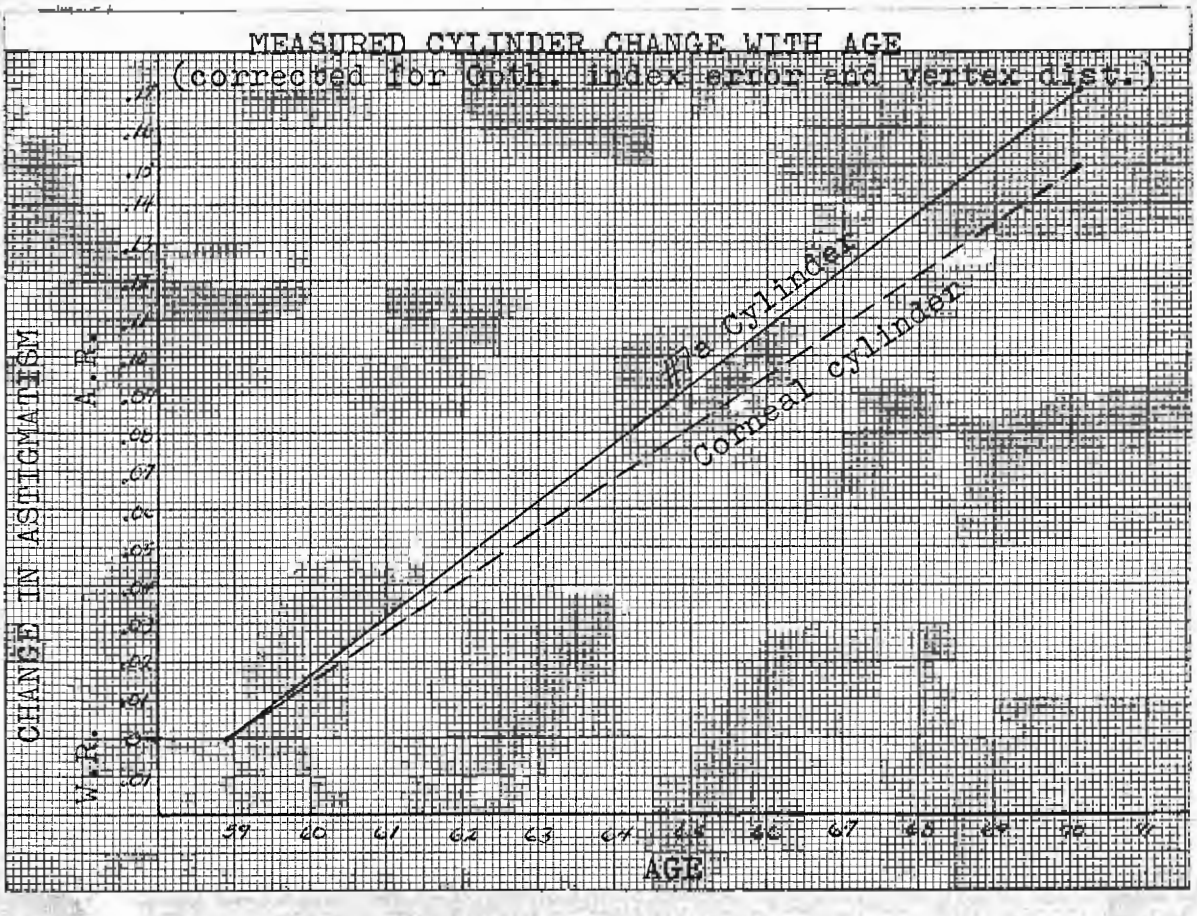
Analysis of change in cylinder :

The average change in cylinder of the cornea over the 11.2 year period is o.135 diopters toward Against-the-rule. The average change in cylinder of the subjective was approximately 0.16 diopter toward Against-the-rule at the spectacle plane or 0.17 diopter toward Against-the-rule at the corneal plane for this same period of time. This leads to the conclusion that the change in astigmatism of the eye toward Against-the-rule, between the ages of approximately 59 and 70, is due mostly to corresponding corneal cylinder change.

The Ophthalmometer is calibrated for an index of 1.3375. The index of the cornea is 1.376. Correcting the corneal cyclinder findings for this error the result is :

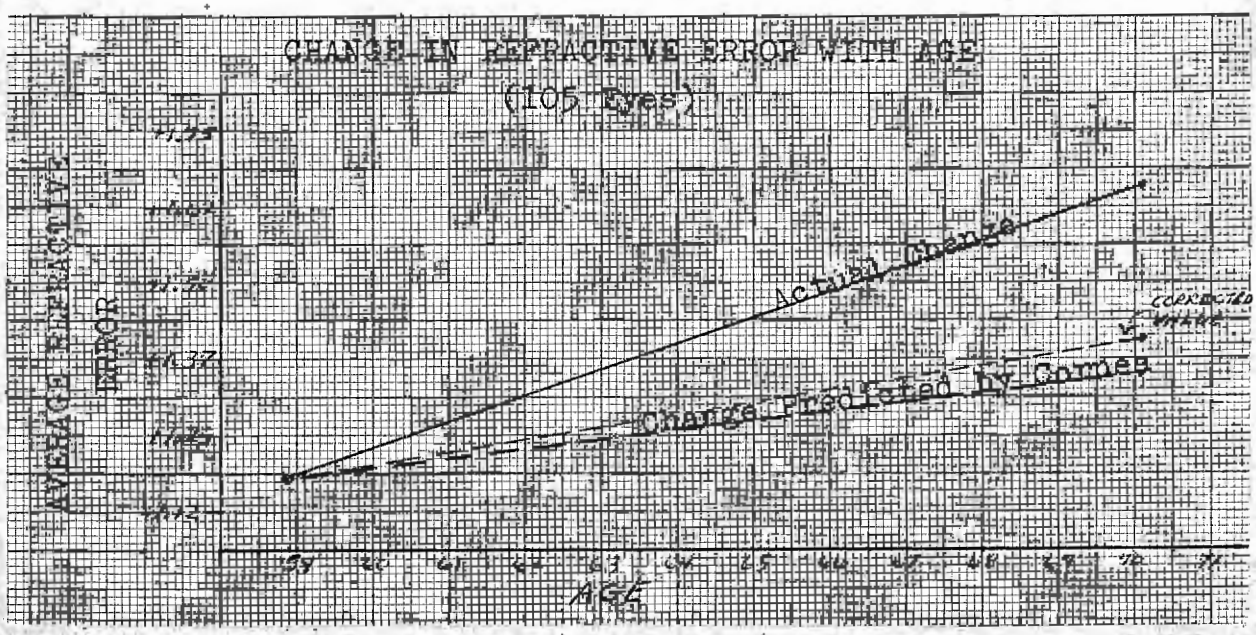
$$\frac{0.376}{0.3375} \times 0.135 \text{ D.} = 0.15 \text{ D. Corneal Cyl.}$$


MEASURED CYLINDER CHANGE WITH AGE
(105 eyes)
CHANGE IN ASTIGMATISM
W.R.
A.R.
Fre Cylinder
Corneal Cylinder
AGE


MEASURED CYLINDER CHANGE WITH AGE
(corrected for Opth. index error and vertex dist.)
CHANGE IN ASTIGMATISM
W.R.
A.R.
Fre Cylinder
Corneal cylinder
AGE

Analysis of change in sphere :

The spherical change toward plus of the corneal readings is much less than the spherical change toward plus of the subjective findings. The change in refraction of the eye toward more plus with age must then be due mostly to factors other than corneal spherical change.



Analysis of "t" score significance test :

From this test it is evident that there is a change in corneal and subjective cylinder toward Against-the-rule, even beyond the 0.001 significance level, between the ages of 59 and 70.

With the 105 eyes there is a close relationship between both the Standard Deviation and "t" score of the corneal and #7a cylinder findings. This suggests

that both changes are due to the same phenomena(Corneal cylinder change).

Analysis of right and left eye calculations :

In using 105 eyes an assumption was made that each eye of a two eyed individual is separate and not similar in its characteristics to the other. The right and left eyes were then calculated separately as a check on this. For both the right eyes and left eyes there is a significant change of cylinder corresponding closely to that change found using all 105 eyes.

Further analysis of change of sphere :

Using the correction factor for the Ophthalmometer findings and applying it to spherical change per year the result is :

$$\frac{0.376}{0.3375} \times 0.018 = .020 \text{ D.}$$ Corneal spherical change per year.

The actual spherical change per year is about .047 diopters. The cornea, then, may account for approximately $\frac{.020}{.047} \times 100$ or 43% of this spherical change with age. The other 57% (.037 D./yr) is due to intraocular changes, probably lenticular in nature.

CONCLUSION

The change in astigmatism of the eye toward Against-the-rule, between the ages of 59 and 70, is due mostly to corneal cylinder change.

The change in refraction of the eye toward more hyperopia, between the ages of 59 and 70, is due mostly to changes in ocular factors other than the cornea.

The cornea accounts for about 43% of spherical refractive change and the remaining 57% is probably due to changes in the crystaline lens.

* Below is the chart used for calculating dioptric powers in 180th and 90th meridians.

Degrees the Cylinder power is removed from 180th or 90th meridian

Cylinder power in 90th or 180th meridian (Diopters)	5°	10°	15°	20°	25°	30°	35°	40°	45°
.25	.247	.242	.232	.220	.205	.187	.168	.148	.125
.50	.494	.485	.465	.440	.410	.375	.335	.295	.250
.75	.743	.727	.698	.660	.615	.562	.503	.443	.375
1.00	.990	.970	.930	.880	.820	.750	.670	.590	.500
1.25	1.24	1.21	1.16	1.10	1.05	.938	.837	.738	.625
1.50	1.49	1.46	1.40	1.32	1.23	1.13	1.01	.885	.750
1.75	1.73	1.70	1.63	1.54	1.44	1.31	1.17	1.03	.875
2.00	1.98	1.94	1.86	1.76	1.64	1.50	1.34	1.18	1.00
2.25	2.22	2.18	2.09	1.98	1.86	1.68	1.51	1.33	1.13
2.50	2.48	2.42	2.32	2.20	2.05	1.88	1.68	1.48	1.25
2.75	2.72	2.67	2.56	2.42	2.26	2.06	2.84	1.62	1.38
3.00	2.97	2.91	2.79	2.64	2.46	2.25	2.01	1.77	1.50
3.25	3.22	3.15	3.01	2.86	2.67	2.44	2.18	1.92	1.63

A. Example :

K = 42.00 @30°/ 43.00 @120°

#7a +2.00 - 1.00 X 45°

1) The K findings have been put under a sign convention to denote correcting cylinder so as to be readily compaired to #7a. The average corneal curvature is about 43.00 D. thus any finding below 43.00 D. is concidered plus (+) and any finding above 43.00 D. is considered minus (-).

2) Elaborating on the above example .
   42.00 @30/43.00 @120

   43.00 c/w -1.00 @30

   a) -1.00 @30 is 30° from 180 so off the graph 75% of its power is in that meridian or get -.75 @180.

   b) With the same reasoning the result @90 is: -.25 @90.

3) Proceeding to the next step.
   43.00 c/w -.75 @180 = 42.25 @180 = +.75 @180
   43.00 c/w -.25 @90 = 42.75 @90 = +.25 @90

   a) REMEMBER SIGN CONVENTION : below 43.00D. is considered plus (+).

4) Example using the subjective finding.
   +2.00 - 1.00 X 45 or +2.00 - 1.00 @135

   a) By looking at the graph it is apparent that ½ of the astigmatism is effective in both 180th and 90th meridians.

   b) The result being :
      +1.50 @ 180

      +1.50 @ 90

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ADDENDA

Additional Information from page 4 footnote #7

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